PERGAMON

Renewable and Sustainable Energy Reviews
6 (2002) 339–366

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Renewable and sustainable energy use in Turkey: a review

Kamil Kaygusuz *

Department of Chemistry, Karadeniz Technical University, 61080 Trabzon, Turkey

Received 31 August 2000; accepted 17 May 2001

Abstract

Turkey is an energy importing nation with more than half of our energy requirements met by imported fuels. Air pollution is becoming a significant environmental concern in the country. In this regard, renewable energy resources are becoming attractive for sustainable energy development and environmental pollution mitigation in Turkey. Turkey's geographical location has several advantages for extensive use of most of these renewable energy sources. Because of this and our limited fossil fuel resources, a gradual shift from fossil fuels to renewables seems to be a serious alternative for Turkey's energy future. This article presents a review of the present energy situation and assesses sustainability, technical, and economical potential of renewable energy sources, and future policies for the energy sector in Turkey. Throughout the paper, problems relating to renewable energy sources, environment, and sustainable development are discussed for both current and future energy investments. The renewable energy potential of the country and its present status are evaluated.

Contents

* Fax: +90-462-325-3195.
E-mail address: kaygukm@turk.net (K. Kaygusuz).

PII: S1364-0321(01)00007-7

Nomenclature

COP	heat pump coefficient of performance
f	fraction of the load met by free energy (%)
I	monthly-average hourly global radiation on horizontal surface (W/m^2)
I_D	monthly-average hourly diffuse radiation on horizontal surface (W/m^2)
I_o	monthly-average hourly extraterrestrial radiation on horizontal surface (W/m^2)
Kton	thousand tonnes
Ktoe	thousand tonnes of oil equivalent
RH	relative humidity (%)
Q	heating load of the building (kW)
T_a	ambient air temperature (°C)
N	number of working days of the series heat pump system per month
η_{col}	collector efficiency
η_{st}	storage efficiency
YDD	yearly degree days

1. Introduction

Energy is essential to the economic and social development and improved quality of life in Turkey as in other countries. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain stagnant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances increasingly needs to be based on efficiency in energy production, transmission, distribution and consumption in the country. On the other hand, electricity-supply infrastructures in Turkey, as in many developing countries, are being rapidly expanded as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth. In contrast, in the coming decades, global environmental issues could significantly affect patterns of energy use around the world, and in Turkey. Any future eforts to limit carbon emissions are likely to alter the composition of total energy-related carbon emissions by energy source in the country [1].

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. The importance of energy in economic development has been recognized universally; the historical data attest to a strong relationship between the availability of energy and level of economic activity. During the past two decades, the risk and reality of environmental degradation have become more apparent. Growing evidence of environmental problems is due to a combination of several factors including environmental impact of human activities and the continued increase of world population. Achieving solutions to environmental problems that we face today requires long-term actions for sustainable development. In this regard, renewable-energy resources appear to be among the most effective solutions. That is why there is an intimate connection between renewable energy and sustainable development [2].

The Kyoto Protocol to the United Nations Framework Convention on Climate Change, agreed to in December 1997, marks an important turning point in efforts to promote the use of renewable energy worldwide. Since the original Framework Convention was signed at the Earth Summit in Rio de Janeiro in 1992, climate change has spurred many countries to step up their support of renewable energy. Even more ambitious efforts to promote renewables are resulting from the Kyoto pact, which includes legally binding emissions limits for industrial countries for the first time, and specifically identifies promotion of renewable energy as a key strategy for reducing greenhouse gas emissions [3].

Coal, oil, and natural gas are all fossil fuels that were formed millions to hundreds-of-millions of years ago from decaying prehistoric plants and animals. Although fossil fuels are still being created today by underground heat and pressure, they are consumed much more rapidly than they are created. Fossil fuels are non-renewable, meaning that they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve. The search for new reserves of fossil fuels has already led to oil exploitation along ocean coasts and other environmentally sensitive areas [4].

Sunlight can be used directly for heating and lighting residential and commercial buildings. The heat of the sun can be harnessed for hot water heating, solar cooling, and other commercial and industrial uses. The sun's heat can also be used to generate electricity, using solar thermal electric power technologies. Sunlight can also be converted directly to electricity using photovoltaic solar cells. Many other forms of renewable energy are indirectly powered by the sun. For example, the sun's heat drives the winds which produce energy that is captured with wind turbines. Winds, in turn, cause ocean waves, producing energy that can be converted to electricity. Sunlight also causes plants to grow, the energy stored in those plants is known as biomass energy (wood, straw, dung, and other plant wastes). Biomass can be converted to liquid or gaseous fuels or burned to produce electricity [4].

Turkey's geographic location has several advantages for extensive use of most of the renewable energy sources. It is on the humid and warm climatic belt, which includes most of Europe, the near east and western Asia. A typical Mediterranean climate is predominant at most of its coastal areas, whereas the climate at the interior part between the mountains that are a part of the Alpine–Himalayan mountain belt is dry with typical steppe vegetation. This is mainly because Turkey is surrounded by seas on three sides: the Black sea to the north, the Marmara sea and Aegean sea to the west and the Mediterranean sea to the south. The average rainfall nationwide is about 650 mm, but this average masks large variations, from about 250 mm in the central and southeastern plateaus to as high as 2500 mm in the northeastern coastal plains and mountains. In the western and southern coastal zones, a subtropical Mediterranean climate predominates, with short, mild and wet winters and long, hot, and dry summers. Arid and semi-arid continental climates prevail in central regions where winter conditions are often extremely harsh, with frequent and heavy snowfall in the higher parts of the Anatolian Plain. On the Black Sea coast, winters are very wet and summers mild and humid. The average annual temperature varies between 18 to 20°C on the south coast, drops to 14 to 16°C on the west coast, and in central parts fluctuates between 4 to 18°C. Local micro-climates can vary widely from the regional averages because of the highly variable terrain and exposure to hot and cold winds [5].

Although Turkey utilises multiple energy resources, it is an energy importing country, since these resources are limited. More than half of the primary energy consumption in the country is met by imports and the share of imports continues to increase each year. Therefore, if the country wants to supply its demand by domestic resources (such as lignite, hard coal, oil and natural gas) the increase in renewable energy resources must be realised in a reasonable time period [6].

The total renewable energy production and consumption of Turkey are equal to each other, varying between 9.3–10.8 million toe each for the 1988–1998 period (Table 1). Their share in total energy production varies on average between 37–43%, while in total consumption between 15–22% for the same period. Among the production of renewables, biomass, including wood and dung, is the highest in 1988, reaching 7.8 million toe. The second highest is hydroelectric production, which reached 3.5 million toe in 1998. The production of geothermal and solar energy is comparably negligible, ranging from 71 to 354 thousand toe between 1988 and 1998

Table 1
Primary energy consumption of Turkey during 1988–1998 (Ktoe)[a]

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Non-Renewable											
Hard coal	5230	4725	6491	6844	6803	6671	6428	6690	9115	8495	8160
Lignite	7932	10207	9765	10572	10743	9918	10331	10605	11187	12280	12414
Oil	22590	22865	23901	23315	24865	28412	27142	29324	30939	30515	32083
Natural gas	1115	2878	3110	3827	4197	4630	4921	6313	7384	9165	10635
Total fossil	36867	40675	43267	44558	46608	49631	48822	52932	58625	60455	63292
Renewable											
Hydropower	2490	1543	1991	1951	2285	2920	2630	3057	3481	3424	3520
Geothermal	58	59	85	86	90	97	115	138	162	179	256
Solar	13	16	21	27	32	38	45	52	80	80	98
Wood	5313	5345	5361	5391	5421	5451	5482	5512	5512	5512	5512
Waste & dung	2527	2504	1847	1821	1788	1697	1627	1556	1533	1512	1492
Total renewable	10401	9467	9305	9276	9616	10203	9899	10315	10768	10707	10878
Total consumption	47268	50142	52572	53834	56224	59834	58721	63247	69393	71162	74170
Total production	24267	25414	25123	25138	26408	26021	26059	26255	26926	27687	28784

[a] Source: [7].

(see Table 1). On the positive side, Turkey's first wind farm was commissioned in 1998, and has a capacity of 1.5 MW. Capacity is likely to grow rapidly, with plans submitted for just under a further 600 MW of independent facilities of which 57 MW is at an advanced stage in negotiations. The majority of proposed projects are located in the Çešme (İzmir) and Çanakkale [6].

2. Energy use in Turkey

The energy demand of Turkey will be doubled between 2000 and 2010, and increase fivefold by 2025. This rapid increase in demand is due to the high economic development rate of Turkey. The estimated amount of investments for the production facilities by the year 2010 is around 45 billion dollars. Transmission and distribution facilities will require an additional 10 billion dollar investment in the same period. The government has undertaken measures to attract both the local and foreign private sector for new investments, and also to transfer operational rights of existing units to the private sector for their renewal and efficient operation [6,7].

Turkey is an energy importing country, with more than half of the energy requirement supplied by imports. Oil accounts for the biggest share of the total primary energy consumption. Due to the recent diversification efforts in the energy portfolio, the use of natural gas, newly introduced into the Turkish economy, has been growing rapidly. Turkey has large reserves of coal, particularly of lignite. The proven lignite reserves are 8.0 billion tons, with estimated total possible reserves of some 30 billion tons. A majority of this lignite, mostly situated in Afšin–Elbistan, Soma and Tunçbilek, has high ash contents in the range of 14 to 42%, high moisture contents ranging from 15 to 50%, and volatile matter contents of 16–38% [6].

In the last 40 years, primary energy consumption has increased by an average of 5% and electricity consumption by 10% annually. Despite these high growth rates, primary energy and electricity consumption are still below the levels of OECD countries.

In 1998, primary energy production and consumption reached 29 and 74 million tons of oil equivalent (mtoe), respectively, (Table 1). The most significant developments in production are observed in hydraulic energy and oil production. Oil production reached its highest level of 4.5 million tons in 1991. Thus, the share of indigenous oil in total oil supply rose to 20 percent. However, this development could not be maintained in subsequent years, and production of oil has entered into a regression period. Figures 1 and 2 show the growth in the primary energy consumption in Turkey.

As of the end of 1998, installed capacity and generation capacity of power plants reached 20 952 MW and 86 247 GW, respectively. As of 1998, electricity demand which amounts to 78 billion kWh was met continuously with a high reserve margin. However, it is crucial to ensure the continuity of investments in order to meet electricity demand without interruption and safely in the coming years, which is expected to improve rapidly. Figure 3 and Fig. 4 show the sectoral electricity and energy demand in Turkey. Figure 5 and Fig. 6 present the installed electric power capacity and electricity generation in Turkey.

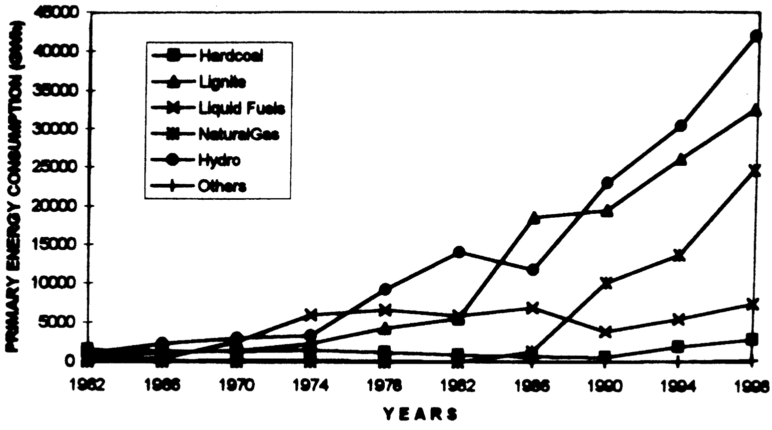

Fig. 1. The growth in the primary energy consumption in Turkey by year.

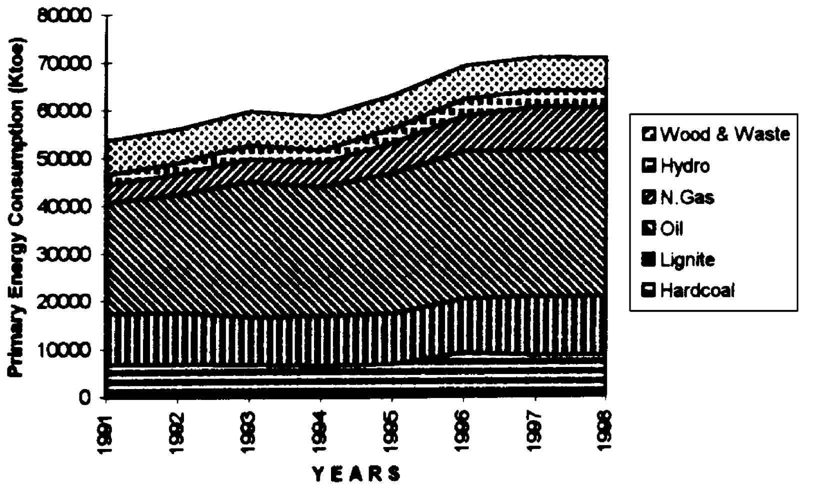

Fig. 2. Primary energy consumption over the years in Turkey.

The findings of the Ministry of Energy and Natural Resources suggest that the primary energy demand will be equivalent to 91 030 kilo tonnes of oil equivalent (Ktoe) in the year 2000, and 314 353 Ktoe in 2020 in Turkey. With this trend, the primary energy consumption will reach 367 780 Ktoe in 2023 and 407 106 Ktoe two years later in 2025. According to the Ministry's production forecasts, domestic production of primary energy will level out at 31 091 Ktoe in 2000 and 79 399 Ktoe by 2020. The projections project domestic generation to top 91 408 Ktoe in 2023 and 95 946 Ktoe in 2025. Table 2 summarizes the findings related to primary energy resources and their domestic production planning.

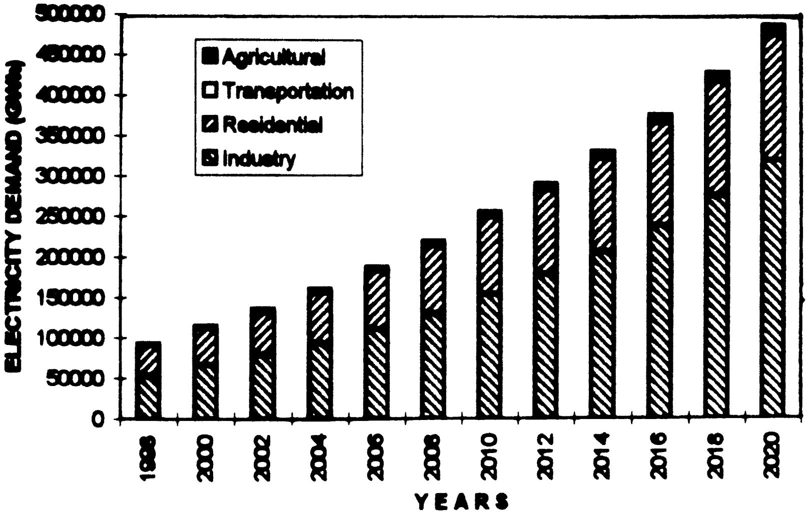

Fig. 3. Sectoral electricity demand in Turkey by years.

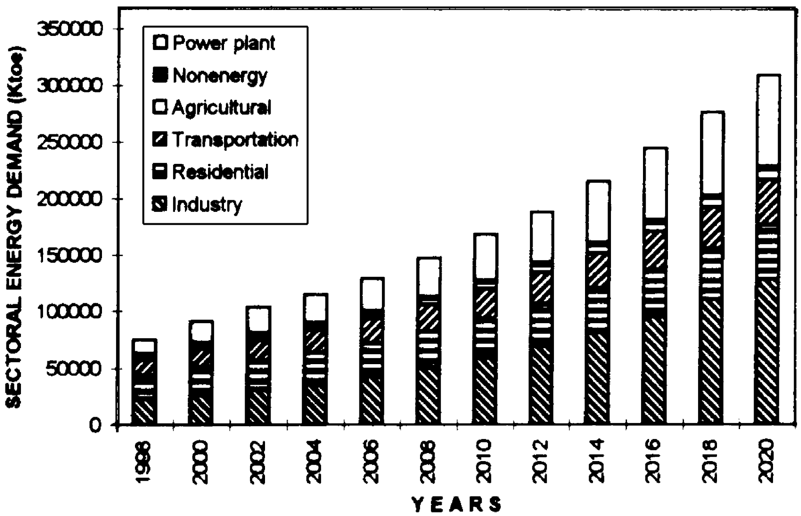

Fig. 4. Sectoral energy demand in Turkey over the years.

3. Renewable energy use and economics

Hydroelectric generation, biomass combustion, solar energy for agricultural grain drying and hot water heating, and geothermal energy have been in use in the country for many years. Domestic water heating is the primary active solar technology. In Turkey, approximately 30 000 solar water heating systems have been installed since the 1980s. This is a minute fraction of the total potential. About 50% of existing

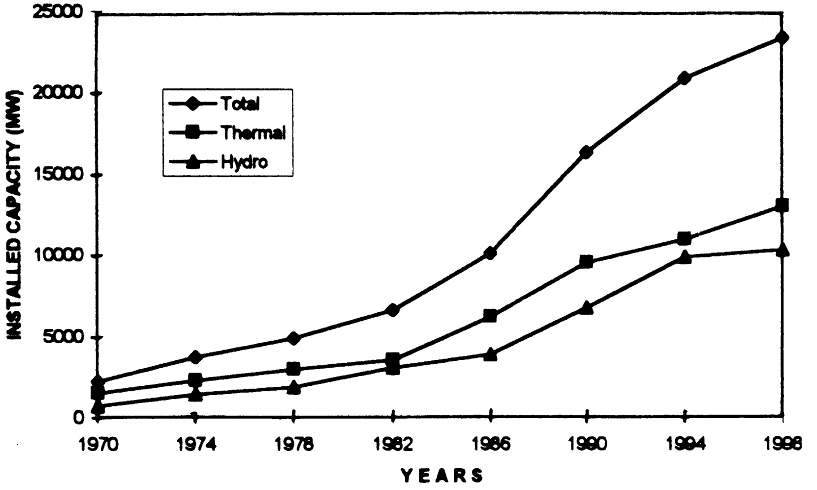

Fig. 5. Installed electric power capacity in Turkey by years.

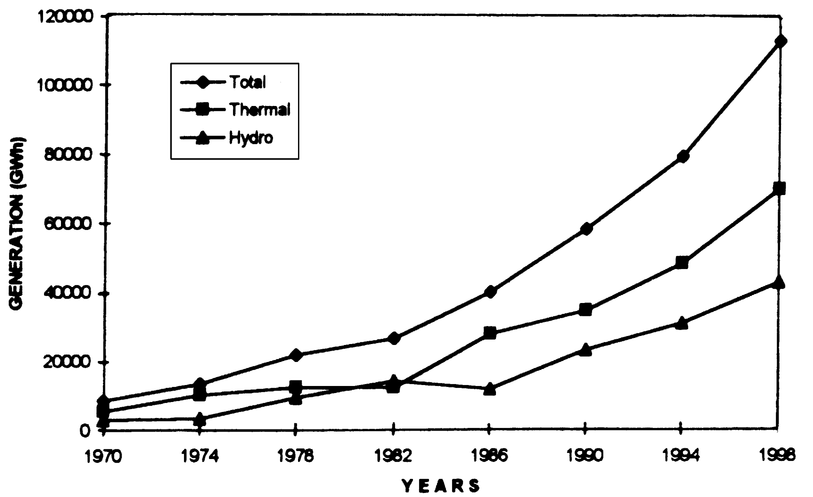

Fig. 6. Electricity generation in Turkey over the years.

dwellings could be fitted effectively with a solar water heater. If this potential were extended to 2025, the deployment of approximately 5 million systems (allowing for a rise in the Turkish housing stock) would be required. This could save an estimated 30 PJ (9.0 TWh) per year of oil, coal and gas and 2.0 TWh per year of electricity, giving a saving of 5.0 million tonnes of CO_2 per year, or just under 1% of current Turkey CO_2 production.

The cost of solar energy collecting systems differ depending upon the type of

Table 2
Primary energy production and consumption (in parenthesis) targets for Turkey between 2000–2025 (Ktoe)[a]

Energy sources	2000	2005	2010	2015	2020	2023	2025
Coal (h.coal+lignit)	17202	21259	28522	31820	39385	42732	45944
	(20256)	(30474)	(50311)	(83258)	(129106)	(198798)	(296997)
Oil and Natural gas	3408	2127	1735	1516	1604	1505	1455
	(59250)	(73256)	(92637)	(112993)	(136365)	(158467)	(179765)
Central heating	253	495	884	1336	2018	2427	2748
	(253)	(495)	(884)	(1336)	(2018)	(2457)	(2748)
Hydropower	3763	5845	7520	8873	9454	10002	10445
	(3763)	(5845)	(7520)	(8873)	(9454)	(10002)	(10445)
Wood and waste	6963	6760	6446	6029	5681	5498	5393
	(6963)	(6760)	(6446)	(6029)	(5681)	(5498)	(5393)
Geothermal	432	1380	3760	4860	4860	5400	5400
	(432)	(1380)	(3760)	(4860)	(4860)	(5400)	(5400)
Nuclear	0.0	0.0	3657	9143	18286	26988	29200
	(0.0)	(0.0)	(3657)	(9143)	(18286)	(26988)	(29200)
Solar	204	459	907	1508	2294	2845	3248
	(204)	(459)	(907)	(1508)	(2294)	(2845)	(3248)
Wind	55	250	620	980	1440	1786	2134
	(55)	(250)	(620)	(980)	(1440)	(1786)	(2134)

[a] Source: [7].

material used for the case of collectors, absorbent plate, and water storage tank. A typical domestic solar energy collecting system used for water heating contains two collectors (total 4–6 m^2 surface area) and a 160–200 litre capacity water storage tank typically costing US$1000 (including installation). In 1997, some 3500 domestic solar heating systems were sold in Turkey. Solar energy collecting systems have an initial cost two to five times higher than alternatives using electricity, LPG, fuel or other solid energy sources. However, their annual repair and maintenance costs are much lower than alternatives. Solar systems with inflated annual costs have a minimum present value of $866. A detailed technical–economic analysis has been performed for solar and biogas space heating systems by several groups for this region [8,9]. The results also provide evidence of the economic viability of biogas systems over the traditional space heating systems of rural Turkey in many instances.

Unlike many of the other renewables, hydroelectricity is a very well-established technology. The water-control systems and the turbo-generators to extract the power are readily available. The many existing installations cover a power range from hundreds of watts (microhydro) to thousands of megawatts. It is very difficult to estimate the exact cost of hydroelectric power. The reason lies in the combination of heavy front-end loading and extremely site-specific construction costs. In other words, the dominant factor in determining the total cost per unit of output is the initial capital cost, and a major part of this can be the civil engineering costs which vary greatly from region to region in Turkey.

Detailed energy and economic comparisons of air-to-air heat pumps and conventional heating systems for the Turkish climate have been reported [10]. This study demonstrated that the heat pump offers distinct economic advantages over the oil and coal-fired boiler systems, but is not an economic alternative to the gas-fired heating system. Because the unit price of the gas is almost 4 times less than that for electricity in Turkey, to become competitive with a gas-fired boiler, either the capital cost of the heat pump must be substantially reduced or its seasonal COP increased by about 60%. (An alternative is to drive it with a gas engine rather than an electric engine.) Table 3 gives the annualised life-cycle cost of heating systems for four different climatic regions in Turkey.

Wood for fuel from forest energy and energy forestry has the potential to make a significant contribution to the future energy mix. At present, forests still provide

Table 3
Annualised life-cycle cost of heating systems

	Annual fuel price escalation rate (%)	Annualised life-cycle cost ($)			
		Ankara	Antalya	Trabzon	Kars
Heat pump	12	384.7	318.1	350.4	485.8
Electrical heater	12	314.2	147.7	229.4	573.6
Gas-fired boiler	12	264.6	222.7	246.3	345.7
Oil-fired boiler	12	448.8	400.0	426.6	542.7
Coal-fired boiler	12	466.5	390.2	430.9	603.1

the major part of energy supplies for cooking and heating in rural areas, and forestry operations are the most important source of employment for some 9 million forest villagers. There are nearly 8,000 sawmills in Turkey as well as over 50 chipboard, plywood and fibreboard plants, most of which operate well under their installed capacities. Raw materials have been depleted because of domestic demand, and around 2.5 million cubic metres of industrial wood are imported annually [5].

4. Water and energy potential in Turkey

The annual average precipitation in Turkey is 643 mm, corresponding to a volume of 500 km^3. The average annual runoff is 186 km^3 (2400 m^3/ha). Subtracting from this figure the estimated water rights of neighbouring countries (with minimum annual streamflow requirements for pollution control, aquatic life and navigation, and topographic and geologic constraints, the annual consumable water potential of 12 km^3 be added to this), the total annual consumable potential is 107 km^3 [11].

Precipitation differs considerably both from year to year and among the river basins. The annual depth of precipitation is as high as 250 cm in the Eastern Black Sea region, and as low as 30 cm in some parts of Central Anatolia. Most of the country's water potential lies in the south-east (28%) and the Black Sea region (8%). Turkey's water resources are concentrated in 26 drainage basins. Table 4 provides the water and energy potential of selected river basins in Turkey. The most important rivers are the Fırat River (Euphrates) and Dicle River (Tigris), both of which are transboundary rivers originating in Turkey and discharging into the Persian (Arabian) Gulf. The Meriç, Çoruh, Aras, Arapçay and Asi Rivers are the other transboundary rivers. Some 22% of the boundaries between Turkey and the neighbouring countries are along international rivers [11].

4.1. *Hydroelectricity*

Hydroelectricity is a principal energy-producing technology, providing some 20% of the world's electricity. In the developing countries, it is even more significant — the proportion rises to around 40%. The generation capacity of large hydroelectric sources can be several times that of a conventional power station. They are proven highly efficient, reliable, and long lasting. They are also very controllable and add an element of storage into an electricity supply system, thereby compensating for the interruptions in other renewable energy sources and for variations in electricity demand. However, the dams and their large reservoirs present major environmental and social impacts [4].

There are identified 436 sites available for hydroelectric plant construction, distributed on 26 main river zones in Turkey. Table 4 summarizes water and hydroelectric energy potential of selected river basins in Turkey. The total gross potential and total energy production capacity of these sites are nearly 50 GW and 112 TWh/yr, respectively. As an average 30% of the total gross potential may be economically exploitable. At present, only 18% of the total hydroelectric power potential is used.

Table 4
Water and energy potential of selected river basins in Turkey[a]

Name of basin	Land area (km^2)	Average rainfall (mm/yr)	Number of dams	Stored water (hm^2)	Installed capacity (MW)	Average generation (GWh)
Susurluk	22399	711.6	25	3509.3	537.0	1697
Gediz	18000	603.0	14	3369.4	250.0	425
B. Menderes	24976	664.3	19	2722.1	214.5	848
B. Akdeniz	20953	875.8	24	1836.6	674.7	2495
Antalya	19577	1000.4	15	2885.3	1251.6	4411
Sakarya	58160	524.7	45	6920.3	1062.5	2362
B. Karadeniz	29598	811.0	24	2518.8	592.7	2110
Yešilırmak	36114	496.5	45	6301.8	1657.6	6468
Kızılırmak	78180	446.1	82	21260.0	2007.0	6512
D. Akdeniz	22048	745.0	11	9121.5	1495.9	5176
Seyhan	20450	624.0	18	6124.5	1885.6	7117
Ceyhan	21982	731.6	25	7719.5	1408.7	4634
Fırat	127304	540.1	83	112791.5	9844.8	38939
D. Karadeniz	24077	1198.2	43	1522.5	3323.1	10927
Çoruh	19872	629.4	20	7544.4	3227.4	10614
Aras	27548	432.4	20	4084.8	585.2	2291
Dicle	57614	807.2	36	30295.0	5081.9	16876
Total Turkey	779452	642.6	702	240763.6	35309.2	124568

[a] Source: [14].

The national development plan aims to harvest all of the hydroelectric potential by 2010. The contribution of small hydroelectric plants to total electricity generation is estimated to be 5–10% [12].

4.2. Southeastern Anatolia Project (GAP)

The Southeastern Anatolia Project (GAP) is one of the largest power generating, irrigation, and development projects of its kind in the world, covering 3 million ha of agricultural land. This is over 10% of the cultivable land in Turkey; the land to be irrigated is more than half of the presently irrigated are in Turkey. GAP is an integrated development project; it is expected to affect the entire structure of the region in its economic, social and cultural dimensions through a process of transformations to be triggered by agricultural modernization. It is envisaged as the means of bridging the gap between the southeastern region and the more advanced areas of Turkey and of increasing the economic standing of the region. The GAP project on the Euphrates and Tigris Rivers encompasses 22 dams and 19 hydroelectric power plants. Once completed, 27 billion kWh of electricity will be generated and 1.7 million hectares will be irrigated [13,15].

The Atatürk Dam has been important in the completion of the Lower Euphrates Project and the GAP project, for it is the water source of the four projects aimed at the irrigation of 852 781 ha. Total area to be irrigated from the Atatürk Dam will reach approximately 1 000 000 ha. The Atatürk Dam, the sixth largest-volume dam (48.7 billion m^3) in the world, is situated in Urfa province. It is a rock packed dam, 169 m high from the river bed and with a 1664 m crest. The body packed volume of the dam is 84.5 million m^3. The Atatürk Dam has eight generators with 300 MW installed capacity for each unit, and the mean value of electrical energy production is 8.5 billion kWh/year [15].

The energy potential of the Tigris and Euphrates is estimated as 12 000 GWh and 35 000 GWh, respectively. These two rivers constitute 10% and 30% of the total hydroelectric energy potential, respectively. The GAP region will be an important electric power producer with 1000 MW installed capacity from Karakaya Dam, 2400 MW installed capacity from Atatürk Dam, and 1360 MW installed capacity from Keban Dam. There are also thermal power plants, fuelled by coal or lignite, in the region. Moreover, there are the Çağçağ III, the small hydroplant power (SHP) with 14.5 MW installed capacity and Kralkızı on the river Tigris with 90 MW capacity. The 185.6 MW Batman HPP are under construction. When these power plants are completed, the installed capacity in the region will reach 5960 MW and the total annual energy 21 900 GWh. The GAP region with this capacity will supply 25% of Turkey’s electricity and 85% of its hydroelectric energy [13].

The Şanlıurfa Irrigation Tunnel system, the largest of its kind with numerous irrigation networks and canal systems, constitutes the physical groundwork in water resources. The tunnel system contains two parallel tunnels, each 26.4 km long. The inner diameter of each tunnel is 7.62 m and the area irrigated by the two tunnels is 476 000 hectares. The irrigation aspect of water resource development efforts will help in removing obstacles to the development of the region. Irrigation is crucially

important for the region's development. Naturally, the changes created by irrigation will affect both the people of the region and the country's welfare positively [14,15].

5. Biomass and fuelwood

Among the renewable energy sources, biomass is important because its share of total energy consumption is still high. Since 1980, the contribution of the biomass resources in the total energy consumption of Turkey dropped from 20 to 10% in 1998. Biomass in the forms of fuelwood and animal wastes is the main fuel for heating and cooking in many urban areas [16,17]. The total recoverable bioenergy potential is estimated to be about 16.92 mtpe. The estimate is based on the recoverable energy potential from the main agricultural residues, livestock farming wastes, forestry and wood processing residues, and municipal wastes that are given in the literature [18]. Table 5 gives total and recoverable bioenergy potential of animal wastes, and Table 6 the total recoverable bioenergy potential in Turkey.

On the other hand, fuelwood is important for rural areas in Turkey as in other developing countries. About half of the world's population depends on wood or other

Table 5
Total and recoverable bioenergy potential of animal wastes in Turkey (1998)[a]

Kind of animal	Total number of animals[a] (thousand head)	Coefficient of conversion (ktoe Per thousand animals)	Total energy potential (ktoe)	Recoverable energy potential (ktoe)
Sheep and goats	75 095	0.048	3604	1081
Donkey, horse, mule & camel	1370	0.235	322	97
Poultry	311 500	0.003	935	281
Cattle and buffalo	12 121	0.245	2970	891

[a] Data obtained from [5].

Table 6
Total recoverable bioenergy potential in Turkey (1998)

Type of biomass	Energy potential (ktoe)
Dry agricultural residue	4560
Moist agricultural residue	250
Animal waste	2350
Forestry and wood processing residues	4300
Municipality wastes and human extra	1300
Firewood	4160
Total bioenergy	16 920

biomass for cooking and other domestic use. In 1998, an estimated 12.5 million steres of fuelwood were produced by the state, with public and private sectors production estimated at about 14.2 million steres. In other words, approximately half of the total demand for fuelwood is met by “unofficial” harvesting in State forests and other agricultural areas.

Studies on energy forests began in 1980 with the “Fourth Five-Year Development Plan” in Turkey. As explained in the “Seventh Five-Year Development Plan”, at present, heating and cooking requirements are generally met by fuelwood in the rural areas of Turkey. Therefore, the “new energy forests” are expected to improve the country’s wood resources, and future programs will come from the government. However, using the forests as a fuelwood source instead of for industrial purposes is much less economical. The wood contains chemical raw materials which can be used in many industries, such as pulp and paper, chemical, and furniture [19].

Although energy forests are considered a renewable energy source, they can be depleted in time due to continued and uncontrolled usage. Short-rotation energy forestry involves growing species of willow planted close together as capping. The crop is planted as cuttings using clonal material with 1–2 m spacing. Management of the crop is intensive, with complete weed control absolutely essential if the crop is to be economically viable. The crop is harvested on cutting cycles of 4–6 years, depending on species and site. This is very important for the country’s economic and social conditions. Because the forest cannot supply sufficient fuel for heating and cooking purposes, plantations of energy forests have to be planned and implemented in the country. The harvest intervals of the energy forests should be longer than 4–6 years. The drawback of the longer cutting cycle is that there are bigger gaps in the income to rural villager or farmer. The economic benefits of the energy forests to the country are summarized in Table 7. Approximately 500 000 tons of fuelwood can be obtained from 230 000 ha of destroyed energy forests in the country [19,20].

Table 7
Predictions of energy forest effects on production and contribution to country’s economy during the Seventh five year development plan in Turkey[a]

Plan years	From existing forest area Forest Area (ha)	Mean wood (Ster/ha)	Total wood (Ster)	From establishing forest area Mean wood (Ster/ha)	Total wood (Ster)
1995	40000	5	200000	79	3160000
1996	45000	5	225000	79	3555000
1997	45000	5	225000	79	3555000
1998	50000	5	250000	79	3950000
1999	50000	5	250000	79	3950000
Total	230000		1150000		18170000

[a] Source: [20].

6. Geothermal energy

Turkey possesses significant potential in geothermal energy. There may exist about 4500 MW of geothermal energy usable for electrical power generation in high enthalpy zones. Heating capacity in the country runs at 350 MWt equivalent to 50 000 households. These numbers can be increased some sevenfold to 2250 MWt (equal to 350 000 households). Turkey is targeting 1.3 million households equivalent, 7700 MWt. Geothermal central heating, which is less costly than natural gas, could be feasible for many regions in the country. In addition, 31 000 MW of geothermal energy potential is estimated for direct use in thermal applications. The total geothermal energy potential of Turkey was about 2268 MW in 1998, but the share of geothermal energy production (both for electrical and thermal uses) is only 1200 MW. There are 26 geothermal district heating systems in Turkey. Main city geothermal district heating systems are in Gönen, Simav and Kıršehir [6].

6.1. Geothermal heat pumps

Heat pumps have advantages because they are able to convert low-grade heat into useful heat. Even in winter, the outside air, water, and ground still retain heat which can be extracted and upgraded by a heat pump. This natural heat can be used for applications from heating buildings to producing hot water. The heat sources are replenished by the sun, therefore the extracted heat can be considered “renewable energy”. Heat pumps can also extract waste heat, e.g. from ventilation air, and make it suitable for reuse. The energy needed to drive a heat pump is one third (or less) of the useful heat produced.

Geothermal heat pumps are relatively new geothermal energy applications that have grown in recent years. They use earth as a heat sink in the summer and as a heat source in the winter. An added benefit of geothermal heat pumps is that they use 25–50% less electricity than conventional heating or cooling systems. Geothermal heat pumps can also reduce energy consumption — and corresponding air pollution emissions — up to 44% compared to air-source heat pumps and up to 72% compared to electric-resistance heating with standard air-conditioning equipment [21].

Detailed technical and economic analyses have been performed for geothermal heat pump heating systems for Turkey [22–24]. These studies show that there is a good potential for geothermal heat pump heating and refrigeration applications in the country. For example, a study conducted by Kilkiš and Eltez [24] indicates that the useful energy extracted from a given geothermal reservoir in a district can be increased by 70% through a hybrid/integrated system compared to a simple open-loop system. Coupled with the proper demand side management design, it is projected that about 115% more customers can be serviced with the same amount of geofluid extracted, without thermal peaking. When district heating and cooling is involved in a geothermal system, heat pumps and hybrid HVAC systems seem to play the key roles.

7. Solar energy

Solar radiation can be converted into useful energy directly, using various technologies. It can be absorbed in solar collectors to provide solar space or water heating at relatively low temperatures. Buildings can be designed with passive solar features that allow solar energy to contribute to their space heating requirements. Small solar collectors are widely used to supply domestic hot water in several countries, including Turkey. It can be concentrated by parabolic mirrors to provide heat at up to several thousand degrees Celcius, for heating or high light fluxes for electricity generation. Solar radiation can also be converted directly into electrical energy using photovoltaic solar cells [4].

Turkey lies in a sun belt between 36° and 42° N latitudes. The yearly average solar radiation is 3.6 kWh/m^2-day, and the total yearly radiation period is approximately 2640 hours, (Table 8) which provides adequate energy for solar thermal applications. In spite of this high potential, solar energy technologies are not now widely used, except for flat-plate solar collectors for domestic hot water production in the coastal regions. In 1998, about 3.0 million m^2 solar collectors were produced and it is predicted that total solar energy production is about 0.080 million ton of oil equivalent (mtoe) [6]. The global solar radiation incident on a horizontal surface and bright sunshine hours are measured by all recording stations in Turkey, and solar radiation models for Turkey are reported [25–30].

7.1. Solar heat pump combination

The largest number of heat pumps currently in use are small reversible units which can provide both heating and cooling, for individual rooms, houses, shops, offices, schools and institutional buildings. Annually, over 10 million units are produced worldwide, with over 65 million units in operation in Japan, the USA, China and Europe. These heat pumps are cost effective in many regions of the world, only

Table 8
Solar and wind energy potential by regions of Turkey[a]

	Annual average wind density (W/m^2)	Annual average wind speed (m/s)	Annual average solar radiation (kWh/m^2-yr)	Sunshine duration (hour/yr)
Marmara	51.91	3.29	1168	2409
Southeast Anatolia	29.33	2.69	1460	2993
Aegean	23.47	2.65	1304	2738
Mediterranean	21.36	2.45	1390	2956
Black Sea	21.31	2.38	1120	1971
Central Anatolia	20.14	2.46	1314	2628
East Anatolia	13.19	2.12	1365	2664
Turkey Average	25.81	2.57	1303	2623

[a] Source: [6].

marginally more than a cooling-only air conditioner. On the other hand, in cold to moderate climates, heating-only heat pumps are used to heat tap water and homes. In commercial buildings and industrial processes, heat pumps are often applied where simultaneous heating and cooling is required, or heating in winter and cooling in summer. Worldwide, over 10 million systems are installed in commercial and institutional buildings [31].

A detailed experimental and analytical study has been performed for solar heat pump combination for domestic heating by Kaygusuz [32–38] for Trabzon, Turkey. Solar energy and heat pump systems reduce the consumption of fossil-fuel resources, and the cost of delivered energy for residential heating. An interesting extension of each is the combining of the two in order to further reduce the cost of delivered energy. Solar heat-pump systems can be classified according to the source of heat that supplies the evaporator of the heat pump as either parallel, series, or dual. In parallel systems, the heat pump receives energy from the outdoor air, and the collected solar energy is supplied directly for either space heating or for heating water. In the series system, solar energy is supplied to the evaporator of the heat pump, thereby raising its temperature and increasing the coefficient of performance (COP). In the dual source configuration, the evaporator is designed so that it can receive energy from either the outdoor air or from the solar-energy store. Our studies show that there is a great potential for using the solar heat pump combination for domestic heating/cooling applications in Turkey. Table 9 gives the theoretical results of air-to-air heat pump systems obtained from different locations in Turkey. Table 10 summarizes the analytical results of solar-assisted series heat pump systems for domestic heating obtained in Trabzon, Turkey.

7.2. Photovoltaic energy

Turkey, currently, does not have an organized photovoltaic (PV) program. Global energy strategies and policies are laid down in periodic five years development plans. The government has no current policy toward PV production. On the other hand, it is encouraged to invest in the energy sector through some financial incentives. Plans for industrial-scale production of PV modules are concentrated in thin-film areas rather than crystalline materials. PV cells are produced in various research establishments in order to study the feasibility of local manufacturing. So far, none of these studies yielded a sufficiently positive result to justify a large production facility in Turkey. The potential of Turkey as a PV market is very large, since the country is very suitable in terms of insolation and large areas of available land for solar farms. There are more than 30 000 small residential areas where solar powered electricity would currently likely be more economical than grid supply. Another potential for the PV market are holiday villages at the coastal areas. These facilities are frequently far from the main grid and require additional power when solar insolation is high. Unfortunately energy demand in Turkey is so large that utilities are concentrating on large conventional power plants and peak load facilities. The five-year development plan, under preparation, foresees a more ambitious program and estimates approximately 40 MW of installed power by the year 2010 [6,39].

Table 9
Some climatic features and air-to-air heat pump COP values for some cities of Turkey[a]

City	Latitude	YDD	Ambient air temperature and heat pump COP values (in parentheses)					
			November	December	January	February	March	April
Adana	36°60′	1230	15.7 (3.49)	11.2 (3.31)	9.3 (3.22)	10.3 (3.28)	12.8 (3.37)	17.0 (3.53)
Ankara	39°57′	3020	7.8 (3.16)	2.5 (2.92)	0.2 (2.80)	1.1 (2.83)	4.7 (3.03)	11.1 (3.30)
Afyon	38°40′	3210	7.3 (3.14)	2.6 (2.93)	0.3 (2.81)	1.7 (2.88)	4.9 (3.04)	10.3 (3.28)
Antalya	36°53′	1165	15.6 (3.48)	11.9 (3.33)	10.1 (3.26)	10.7 (3.29)	12.8 (3.37)	16.4 (3.51)
Bolu	40°40′	3456	7.2 (3.13)	2.8 (2.94)	0.2 (2.80)	1.5 (2.86)	4.3 (3.00)	9.3 (3.22)
Çanakkale	40°10′	2142	12.2 (3.34)	8.4 (3.20)	6.1 (3.09)	6.6 (3.13)	7.8 (3.16)	12.3 (3.35)
Erzurum	39°60′	5060	2.1 (2.90)	−5.2 (2.50)	−8.4 (2.32)	−7.1 (2.40)	−3.1 (2.62)	5.1 (3.03)
Gaziantep	37°10′	2546	9.4 (3.23)	4.5 (3.02)	2.6 (2.92)	3.8 (2.98)	7.2 (3.13)	12.8 (3.37)
İstanbul	40°59′	2451	12.0 (3.34)	8.0 (3.17)	5.2 (3.04)	5.5 (3.05)	6.7 (3.14)	10.9 (3.30)
İzmir	38°24′	1510	14.3 (3.42)	10.6 (3.28)	8.7 (3.18)	9.6 (3.25)	11.0 (3.28)	15.5 (3.48)
Kars	40°36′	5584	0.9 (2.81)	−7.5 (2.38)	−11.6 (2.14)	−10.0 (2.24)	− 4.2 (2.56)	4.5 (3.02)
Kayseri	38°40′	3382	5.9 (3.06)	1.2 (2.84)	−1.6 (2.71)	0.1 (2.78)	4.4 (3.01)	10.7 (3.29)
Ordu	40°60′	2272	12.3 (3.35)	9.7 (3.26)	6.5 (3.12)	6.4 (3.11)	7.9 (3.17)	11.2 (3.31)
Sinop	42°00′	2310	13.0 (3.38)	9.6 (3.25)	7.2 (3.15)	6.8 (3.13)	7.2 (3.13)	10.2 (3.27)
Trabzon	41°10′	1652	16.0 (3.50)	13.0 (3.38)	10.7 (3.28)	9.5 (3.24)	10.2 (3.27)	11.9 (3.38)
Zonguldak	41°27′	2394	11.9 (3.33)	8.8 (3.19)	6.1 (3.08)	6.3 (3.10)	7.3 (3.14)	10.9 (3.30)

[a] The COP values were calculated by using equation (12) in [32] and all values are averages taken over a month.

Table 10
The theoretical results of the solar-assisted in series heat pump systems during the heating season in Trabzon[a]

Month	Q (kW)	T_a (°C)	RH(%)	I	I_o	I_D	N	COP	η_{col}	η_{st}	f
November	1915	12.0	76.2	5.60	13.40	2.56	19	4.50	0.63	0.62	0.66
December	3160	8.4	68.4	4.12	12.38	2.20	15	4.30	0.55	0.58	0.55
January	4376	4.6	66.7	5.42	14.66	2.30	18	4.20	0.50	0.60	0.65
February	4360	3.2	67.3	6.26	20.22	3.39	22	4.10	0.58	0.64	0.70
March	3012	8.6	65.3	7.35	22.92	4.67	18	4.20	0.60	0.62	0.72
April	2210	11.3	72.1	11.60	35.74	6.16	20	4.50	0.59	0.64	0.74

[a] All values are averages taken over a month.

8. Wind energy

In Europe, as much as 25% of its current electricity demand could be met from wind energy sources [4]. There are a number of regions in Turkey with relatively favorable wind speeds (see Table 8). These have been classified into six wind regions, with a low of about 3.5 m/s and a high of 5 m/s at 10 m altitude. These correspond to a potential power production of between 1000 and 3000 kWh/(m^2 yr). The most attractive sites are the Marmara Sea region, Mediterranean Coast, Agean Sea Coast, and Anatolia inland [40–43]. Turkey's first wind farm was commissioned in 1998, and has a capacity of 1.5 MW. Capacity is likely to grow rapidly, as plans have been submitted for just under a further 600 MW of independent facilities. The majority of proposed projects are located in the Çešme, İzmir and Çanakkale regions. The electrical power resources survey and development administration (EIE) carries out wind measurements at various locations to evaluate wind-energy potential throughout Turkey, and are compiling a wind energy atlas (in cooperation with other organisations). Approval of independent wind energy projects requires at least a six month history of wind measurements. Table 2 presents primary energy production and consumption targets for Turkey. From Table 2, the use of geothermal, wind, and solar energy is expected to increase between the years 2000–2025. For example, in year 2025, 25% of the total production will be provided by hydro, geothermal, wind, solar, wood and waste.

9. Sustainable development

A secure supply of energy resources is generally agreed to be a necessary but not sufficient requirement for development within a society. Furthermore, sustainable development demands a sustainable supply of energy resources. The implications of these statements are numerous, and depend on how "sustainable" is defined. Sustainable development within a society requires a supply of energy resources that, in the long term, is readily available at reasonable cost and can be utilized for all

required tasks without causing negative societal impacts. Supplies of energy resources such as fossil fuels (coal, oil, natural gas) and nuclear fuels (uranium and thorium) are generally acknowledged to be finite; other energy sources such as solar, hydropower, biomass and wind are generally considered renewable and therefore sustainable over the relatively long term [44].

The world's proven reserves of oil have increased from some 540 billion barrels in 1969 to just over 1000 billion barrels in 1992, but this is not to say that potential reserves are unlimited. The earth has been surveyed in great detail by the oil companies, and the easiest, cheapest and most promising reservoirs have all been found. Except for the huge reserve of oil in the Middle East, the world's most readily exploitable sources of oil and gas have been used up. It is only because of this that such difficult sources of oil as the North Sea and Alaska have become economically viable: that is, the price of oil has risen enough to make them worth exploiting. On the other hand, in the case of natural gas, the situation is somewhat different, because of the massive reserves in the former Soviet Union. This region holds some 40% of the world's gas reserves, and another 40% of gas is in the OPEC region. In contrast, the world's coal reserves are much larger and much more evenly distributed. In 1992 the world reserve/production ratio for coal was over 200 years. Unfortunately, coal has disadvantages compared to oil and gas because it produces more CO_2, SO_2 and NO_x per unit of energy released than is the case with gas and oil [4].

Fossil fuel reserves, production rates in 1998, and estimated sustainability years are summarized in Table 11. Turkey possesses few fossil fuel reserves. Excluding lignite, the coal, oil, and natural gas reserves in the country are quite scant and are far from meeting the domestic demand. For longer timescales, lignite deposits are also limited. Turkey's total extractable reserves of coal, oil, natural gas, asphaltite,

Table 11
Fossil fuel reserves, production rates in 1998, and sustainability years in Turkey

Fuel	Reserves (Mton) Recoverable	Total possible	Production in 1998 (kton/yr)	Sustainability years
Coal	170	1,126	1,380	55[a]
Lignite	7,120	8,130	12,909	105[b]
Petroleum	130	130	3,385	30[c]
Natural gas (10^6 m^3)	20	20	565	24[d]
Asphalts	40	75	23	120
Bitumens	830	1,490	–	–
Uranium (kton)	9,2	9,2	–	–
Thorium (kton)	–	380	–	–

[a] Future production as that of 1998, based on the last 15 yr.
[b] With 0.005% increase in future production, based on the last 10 yr.
[c] With 0.004% increase in future production, based on the last 15 yr.
[d] With 0.09% increase in future production, based on the last 10 yr.

and bitumen amount to 2454 Mtoe (Table 11). The average growth rates of the periods during which production rates have been stably increasing are included in the estimation of sustainability years. Technically and economically, recoverable reserves are also included in the estimation by using yearly energy statistics for Turkey. The results for each fossil fuel are given in Table 11. As shown, unless new fossil-fuel deposits are discovered or the possible reserves become feasibly extractable, indigenous fossil fuels have very limited lifetimes.

Power has become an essential part of our everyday lifestyles. The liability falls on everyone who consumes energy. The economy and the desire to improve our atmosphere and ecosystem demand that we be wise when making decisions. This reasoning must be practised by everyone, from the power companies on down to each individual consumer. The utility companies must search out and utilise every technology and system update that will increase its efficiency. The consumer must do the same and not be wasteful in energy use. In addition, supply-side management techniques generally seem to benefit the individual using the system or technology. Solar collectors, geothermal and wind turbines, biogas, and heat pumps are all excellent technologies, but individuals (or companies) must be systematic in analysing their needs and in choosing the correct system to best meet the desired purposes. On the other hand, the environmental concerns are an important factor in sustainable development. For a variety of reasons, activities which continually degrade the environment are not sustainable over time. A large portion of the environmental impact in a society is associated with its utilisation of energy resources. Therefore, improved energy efficiency in power plants leads to reduced energy losses and reduced environmental pollution [45].

10. Environmental effects of energy use in Turkey

Air pollution is becoming a great environmental concern in Turkey. Air pollution from energy utilization in the country is due to the combustion of coal, lignite, petroleum, asphaltite, natural gas, wood, and agricultural and animal wastes. In Turkey, the CO_2 emissions totalled about 73 million tons in 1998. The amount of carbon emission per person was about 1020 kg, and per square kilometer, 105 tons. The total amount of carbon emissions will increase to 83–93 million tons in the year 2000 and to 128–166 million tons in 2010, according to the probable portion approach model [6,46]. On the other hand, the level of carbon emissions is less by 14–16% with the economic sensitivity approach method, which gives these amounts as 77–86 million tons in 2000 and 110–140 million tons in 2010 (Table 12).

Owing mainly to the rapid growth of primary energy consumption and the increasing use of domestic lignite, SO_2 emissions in particular have increased rapidly in recent years in Turkey. According to the estimates given by the Ministry of Energy, total SO_2 emissions in Turkey were in the range of 2100 million tons in 1998. The major source of SO_2 emissions is the power sector, contributing more than 50% of the total emissions. As reported [46,47], SO_2 concentrations in the flue gas of some lignite-fired power stations are extremely high and differ notably between power

Table 12
Predicted emissions of carbon from combustion sources in Turkey

	1998	2000 Low	Normal	High	2010 Low	Normal	High
Emission (million tons)							
Possible portion	78.6	83.4	88.2	92.7	128.2	145.9	165.7
Economical portion	72.7	77.5	81.6	85.8	109.5	123.1	139.4
Emission (ton/km^2)							
Possible portion	102.2	107	113	119	164	187	212
Economic portion	94.2	99	105	110	140	158	179
Emission (kg/person)							
Possible portion	1102	1202	1271	1336	1543	1755	1994
Economic portion	1017	1117	1176	1236	1318	1482	1677

plants, owing to the variation of the sulphur content of the fuels. Table 13 gives the amount of SO_2 emissions from combustion sources in 1998, 2000, and 2010 for Turkey.

Although the NO_2 emissions are lower than SO_2 emissions in Turkey, they have increased rapidly, following the growth in energy consumption. A similar upward trend of NO_2 emissions has been observed in many European Community countries as well, resulting mainly from the increased traffic density. In Turkey, nearly 50% of the total NO_2 emissions are from the transportation sector, while less than 20% are caused by power generation. Per capita NO_2 emissions are still much lower in Turkey than in the European Community countries, i.e., less than one-third of these countries average. Table 14 provides the level of NO_2 emissions in 1998, 2000 and 2010 (predicted) for Turkey [6,46,47].

Table 13
Predicted emissions of SO_2 from combustion sources in Turkey

	1998	2000 Low	Normal	High	2010 Low	Normal	High
Emission (thousand tons)							
Possible portion	2235	2337	2492	2641	2356	2737	3163
Economical portion	2064	2165	2303	2439	1977	2265	2609
Emission (ton/km^2)							
Possible portion	2.2	3.0	3.2	3.4	3.0	3.5	4.1
Economic portion	1.9	2.8	3.0	3.1	2.5	2.9	3.3
Emission (kg/person)							
Possible portion	32.4	33.7	35.9	38.1	28.4	32.9	38.1
Economic portion	30.2	31.2	33.2	35.1	23.8	27.3	31.4

Table 14
Predicted emissions of NO_2 from combustion sources in Turkey

	1998	2000 Low	Normal	High	2010 Low	Normal	High
Emission (thousand tons)							
Possible portion	1219	1319	1389	1461	2027	2280	2565
Economical portion	1117	1217	1278	1343	1746	1950	2187
Emission (ton/km^2)							
Possible portion	1.3	1.7	1.8	1.9	2.6	2.9	3.3
Economic portion	1.2	1.6	1.6	1.7	2.2	2.5	2.8
Emission (kg/person)							
Possible portion	17.4	19.0	20.0	21.1	24.4	27.4	30.9
Economic portion	15.3	17.5	18.4	19.4	21.0	23.5	26.3

11. Conclusions

To achieve even the modest environmental goals of the Kyoto Protocol requires the sustained and orderly commercial development of viable renewable-energy options. It is not enough for government to support the development of renewable energy technologies, it must also support their commercial application in the country. Just as the support of renewable-energy research and development is an appropriate use of public funds, so too is investing in the products of the research programs. Like health care, education, the construction and maintenance of roads, and national defense, renewable energy is good public policy. The promise of renewable energy is that it offers alternatives to many of the environmental and social problems associated with fossil and nuclear fuels. Whilst it appears to be technically possible to replace all fossil and nuclear fuels with renewable energy sources, on the basis of present and projected costs the energy supplied would be substantially more expensive than it is now. However, there is a strong argument that conventional fuels are currently underpriced because they do not include provision for their environmental effects.

Renewable energy resources and their utilisation in Turkey are intimately related to sustainable development. For the governments or societies to attain sustainable development, much effort has to be devoted to utilising sustainable energy resources in terms of renewables. Environmental concerns should also be addressed. The following conclusions and directions are drawn for renewable and sustainable energy for Turkey:

- There are a number of environmental problems facing our country today. These problems span a continuously growing range of pollutants, hazards, and ecosystem degradation throughout Turkey. Both government agencies and non-governmental organisations must work together to institute policies for and use of renewable energy — as appropriate for Turkey.
- Renewable energy technologies that possess potential as cost-effective and

environmentally friendly alternatives to conventional energy generation systems should be implemented. Governmental energy institutions and agencies should recognise the benefits of investment into these energy alternatives.
- Hydropower is a proven energy source — reliable and cost effective. The service lifetime of hydroelectric power plants is long in comparison to other types of energy generation, making water power economically attractive.
- Solar and wind energy represent a considerable opportunity and potential for our country. They can contribute a significant portion of our future energy needs.
- Turkey must develop projects for sustainable management of natural resources and income generation in rural areas, ensuring positive environmental impacts.
- Turkey's rising population requires the definition and successful implementation of sustainable development policy. However, acceptable sustainable development could only be achieved if it brings economic as well as environmental benefit to the population.
- In order to reduce CO_2, SO_2, and NO_x emissions from fossil fuels, utilities should increase energy savings and efficiency implementing measures in all power plants. Additionally, cogeneration systems should be used.
- Exploration for new coal fields should continue. Special importance should be given for the use of the most proper burning technologies for Turkish lignites to obtain a clean environment for the future of the country.
- River type small hydroelectric power plants are important to Turkey's energy portfolio. This is well matched to domestic manufacturing and residential energy needs.
- Biomass energy (especially wood fuels) presents a considerable opportunity for Turkey to meet a significant part of our future energy needs from this sustainable energy source.

Acknowledgements

This work was supported by the Karadeniz Technical University Research fund.

References

[1] Kaygusuz K. Energy situation, future developments, energy saving, and energy efficiency in Turkey. Energy Sources 1999;21(5):405–16.
[2] Dinçer I. Renewable energy and sustainable development: a crucial review. Renewable and Sustainable Energy Reviews 2000;4:157–75.
[3] Flavin C, Dunn S. Climate of opportunity: renewable energy after Kyoto. Renewable Energy Policy Project, 1998. http:/www.repp.org/
[4] Boyle G, editor. Renewable energy: power for a sustainable future. Oxford: Oxford University Press; 1998. pp. 1-40.
[5] State Institute of Statistics (DIE). Statistic yearbook of Turkey in 1997. Republic of Turkey (Ankara) Prime Ministry, 1998.
[6] Turkish Industrialists' and Businessmen's Association (TUSIAD). Turkey's energy strategy on the

brink of the 21st century: an overview (in Turkish). This report prepared by Ultanir, M.Ö. Istanbul, Turkey, 1998.
[7] World Energy Council Turkish National Committee (WECTNC). Energy report of Turkey in 1998, Ankara (Turkey) 1999.
[8] Tašdemiroğlu E. Economics of biogas space heating systems in rural Turkey. Bioresource Technology 1991;36:147–55.
[9] Özsabuncuoğlu IH. Economic analysis of flat plate collectors of solar energy. Energy Policy 1995;23:755–63.
[10] Kaygusuz K. Energy and economic comparisons of air-to-air heat pumps and conventional heating systems for the Turkish climate. Applied Energy 1993;45:257–67.
[11] Bayazit M, Avcı I. Water resources of Turkey: potential, planning, development and management. Water Resources Development 1997;13(4):443–52.
[12] Kaygusuz K. Hydropower potential in Turkey. Energy Sources 1999;21:581–8.
[13] Bağıš AI. Turkey's hydropolitics of the Euphrates–Tigris basin. Water Resources Development 1997;13(4):567–81.
[14] State Water Works (DSI). Statistical bulletin with map in 1997, Ankara, Turkey, 1998.
[15] Kaygusuz K. Energy and water potential of the Southeastern Anatolia Project (GAP). Energy Sources 1999;21:913–22.
[16] Türker MF, Kaygusuz K. Socio–economic analysis of fuelwood use in a rural area of Turkey. Bioresource Technology 1995;54:285–90.
[17] Türker MF, Ayaz H, Kaygusuz K. Forest biomass as a source of renewable energy in Turkey. Energy Sources 1999;21(8):705–14.
[18] Kaygusuz K. Rural energy resources: applications and consumption in Turkey. Energy Sources 1997;19(6):549–58.
[19] Kaygusuz K, Türker MF. The use of wood as an energy source in Turkey. Energy Sources 1998;20(7):605–14.
[20] State Planning Organization (SPO). Seventh Five-Year Development Plan. Forestry Special Impression Commission Report [in Turkish]. DPT, Ankara, Turkey, 1995.
[21] US Department of Energy (DOE). Geothermal heat pumps (report), DOE/GO, 1998.
[22] Kilkiš IB. Efficient and effective utilization of geothermal energy in Denizli and the vicinity (in Turkish). Technical Report, No. 2, Springfield, Missouri: Heatway, 1994.
[23] Keçeciler A, Acar Hİ, Doğan A. Thermodynamic analysis of the absorption refrigeration system with geothermal energy: an experimental study. Energy Conversion and Management 2000;41:37–48.
[24] Kilkiš IB, Eltez M. Advances in geothermal energy use. ASHRAE Journal 1996;38:1–7.
[25] Ögelman H, Ecevit A, Tašdemiroğlu E. A new method for estimating solar radiation from bright sunshine data. Solar Energy 1984;33:619–25.
[26] Tašdemiroğlu E, Ecevit E. Comparisons of the hourly and daily global irradiances of Turkey on non-horizontal surfaces. Energy Conversion and Management 1985;25:119–26.
[27] Tiris M, Tiris C. Analysis of solar radiation data for Gebze, Turkey. Energy Conversion and Management 1996;38:179–86.
[28] Kaygusuz K, Ayhan T. Analysis of solar radiation data for Trabzon, Turkey. Energy Conversion and Management 1999;40:545–56.
[29] Şen Z, Şahin AD. Solar irradiation polygon concept and application in Turkey. Solar Energy 1999;68(1):57–68.
[30] Ertekin C, Yaldız O. Estimation of monthly average daily global radiation on horizontal surface for Antalya (Turkey). Renewable Energy 1999;17(1):95–102.
[31] International Energy Agency Heat Pump Centre. Heat Pumps: an opportunity for reducing the greenhouse effect (Brochure), The Netherlands, 1997.
[32] Kaygusuz K, Gültekin N, Ayhan T. Solar-assisted heat pump and energy storage for domestic heating in Turkey. Energy Conversion and Management 1993;34:335–46.
[33] Kaygusuz K. Performance of solar-assisted heat-pump systems. Applied Energy 1995;51:93–109.
[34] Kaygusuz K. Investigation of a combined solar-heat pump system for residential heating. Part 1: experimental results. Int. J. Energy Res. 1999;23:1213–23.

[35] Kaygusuz K. Investigation of a combined solar-heat pump system for residential heating. Part 2: simulation results. Int. J. Energy Res. 1999;23:1225–37.
[36] Kaygusuz K. Experimental and theoretical investigation of a solar heating system with heat pump. Renewable Energy 2000;21:79–102.
[37] Çomaklı Ö, Bayramoğlu M, Kaygusuz K. A thermodynamic model of a solar assisted heat pump system with energy storage. Solar Energy 1996;56(6):485–92.
[38] Kaygusuz K. Calculation of required collector area of a solar-assisted series heat pump for domestic heating. Energy Sources 2000;22(3):247–56.
[39] International Energy Agency (IEA). Implementing agreement on photovoltaic power systems. Annual Report, Rome, 1995.
[40] Tašdemiroğlu E. Wind energy assessment in Turkey. Energy 1987;12:1–9.
[41] Şen Z, Şahin AD. Regional assessment of wind power in western Turkey by the cumulative semivariogram method. Renewable Energy 1997;12:169–77.
[42] İncecik S, Erdoğmuş F. An investigation of wind power potential in western coast of Anatolia. Renewable Energy 1994;6:863–5.
[43] Borhan Y. Mesoscale interactions on wind energy potential in the northern Aegean region: a case study. Renewable and Sustainable Energy Reviews 1998;2:353–60.
[44] Dinçer I, Rosen MA. A worldwide perspective on energy, environment and sustainable development. Int. J. Energy Res. 1998;22:1305–21.
[45] Kaygusuz K, Kargı H, Kaygusuz A. Role of the clean energy potential for energy savings and air pollution control in Turkey. Energy Sources 1996;18:885–901.
[46] Şahin, V. Future view of Turksh energy sector: supply, demand and policies (in Turkish) published by TUSIAD, Istanbul, 1994.
[47] Plinke E, Atak M, Haasis HD, Rentz O. Cost-efficient emission control strategies for the Turkish energy system. Energy 1992;17:377–95.